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# MICROBIALITE MORPHO-STRUCTURES AND BIOGENIC ACCRETION MECHANISM OF THE EOCENE IRONSTONES OF GABAL GHORABI MINE AREA, EL BAHARIYA DEPRESSION, WESTERN DESERT, EGYPT

**EL AREF, M. M.*, MESAED, A. A.*, KHALIL, M. A.**, AND SALAMA, W. S.****
***Geology Department, Faculty of Science, Cairo University**
****Egyptian Iron and Steel Company**

## ABSTRACT

**Ghorabi ironstones are deposited in quiet water lagoonal and peritidal environments and interrupted by agitated periods of tidal and/or storm hydrodynamic forces. The study ironstone succession includes the following five facies; mud, stromatolitic, fossillferous, nummulitic-ooidal-oncoidal and nummulitic ironstone facies. The present work concentrates on the role of microbes in the precipitation and diagenesis of the Fe- oxyhydroxides and the accretion mechanism of the various ironstone microbial structures. The microbes and the associated ironstone sediments are studied using polarized and reflected light microscopes as well as SEM. Three main microbial structures are recognized. These include: 1) ferruginous stromatolitic microbialites that are subdivided into two sub-types: a) bedded biostromal (stratiform) stromatolites and b) digitate stromatolites. This type grows in intertidal areas of low water energy and low sedimentation rate, 2) ferriferous concentrically laminated microbialites, including cored and uncored Fe-oncoids (>2 mm in diameter), micro-oncoids and ooids (<2 mm in diameter). The cored Fe-oncoids and ooids contain central nuclei that are transported, accumulated and *in situ* reworked by tidal and/or storm-induced currents. Their cortices have even, slightly crenulated and club-shaped micro-stromatolitic forms they are developed in inter-storm quiet water periods. The uncored Fe-oncoids and ooids are developed as *in situ* biogenic grains within the microbial mat structures or grown at the expense of the original amorphous Iron oxyhydroxide matrix during the early diagenetic processes and 3) ferriferous peloids are associated with Fe ooids and they represent the initial stage of ooid growth. The coccoid and filamentous cyanobacteria are the main microbes affecting the precipitation of Fe-oxyhydroxides and ferrihydrite through either simple physical trapping and blockage (baffling) or biochemical adsorption on and/or in extracellular polymeric substances (EPS) to become agglutinated and stabilized against erosion.**

**Keywords: Microbialite, morpho-structures, Eocene ironstones, G. Ghorabi, El Bahariya, Egypt**

## INTRODUCTION

**Microbialites are "organo-sedimentary deposits that have accreted as a result of benthic microbial community trapping and binding detrital sediments and /or forming the locus of mineral precipitation" (Burne and Moore, 1987). The ferric Iron-encrusted microbial communities are frequently observed in deposits (biolaminated or not) and iron formation from Early Proterozoic to modern ages (Dabanayake and Krumbein, 1986; Bourque and Boulvain, 1993 and Mamet *et al.*, 1997). The microbial precipitation of iron oxyhydroxides (ferrihydrites) is widespread in nature and the Fe bacteria that associated with ferric Fe precipitates occur in fresh and marine environments (Ehrlich, 1990). The simple presence of pure iron oxyhydroxides in an ancient sedimentary environment might be considered as an Indicator of microorganisms performing an *in situ* biomineralization process, even if the microorganisms have become invisible because they have not fossilized. Many iron ores that are thought to be the result of ancient high-temperature hydrothermal process may, In fact, be the result of ancient low-temperature microbial activity (Gillan and De Ridder, 2001).**

**Ghorabi-Nasser area is located at the extreme northeastern corner of the Bahariya Depression at about 25 km west of El Bahariya-Cairo road (Fig. 1). The area is a topographically high feature, attaining about 2.3 sq km and is completely separated from the surrounding Eocene carbonate scarp by deep structural and erosional wadis. To the north, the structurally controlled fault wadi separates Gabal Ghorabi from the scattered hills of Nasser area and the karstified Eocene carbonates (Fig. 2). At the south, Gabal Ghorabi directly overlooks the Bahariya Depression and the surrounding wadis are opened into the main Depression. The core of Gabal Ghorabi is made up of the Cenomanian clastics of the Bahariya Formation, which is unconformably overlain by Eocene ironstone succession and the related duricrusts. In some places, discontinuous Oligocene pebbly sandstone beds unconformably overlie the Eocene ironstone succession.**

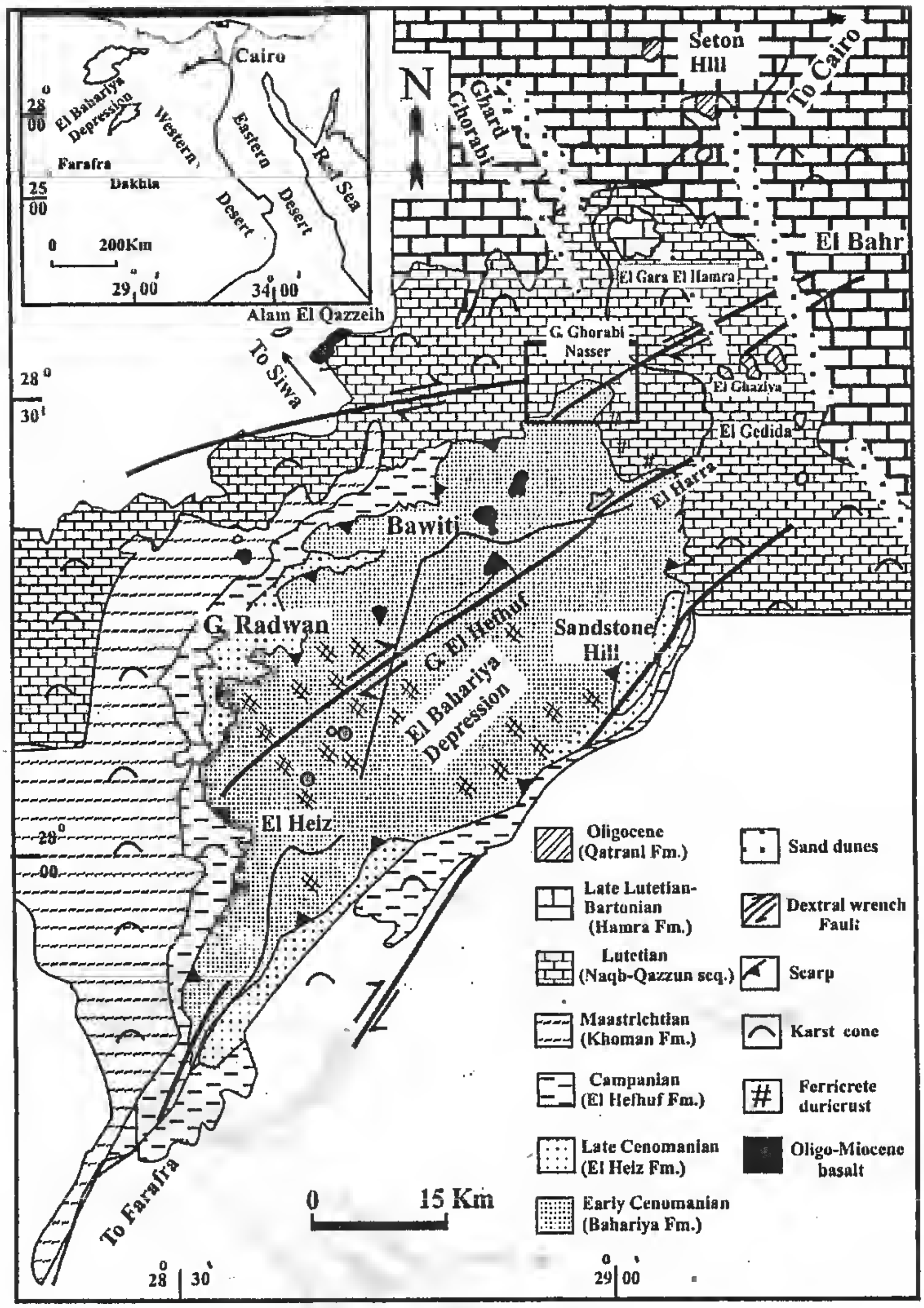


Fig.1. Geological map of El Bahariya Depression (modified after Hermina et al., 1989, detailed structural elements are shown in Sehim, 1993).

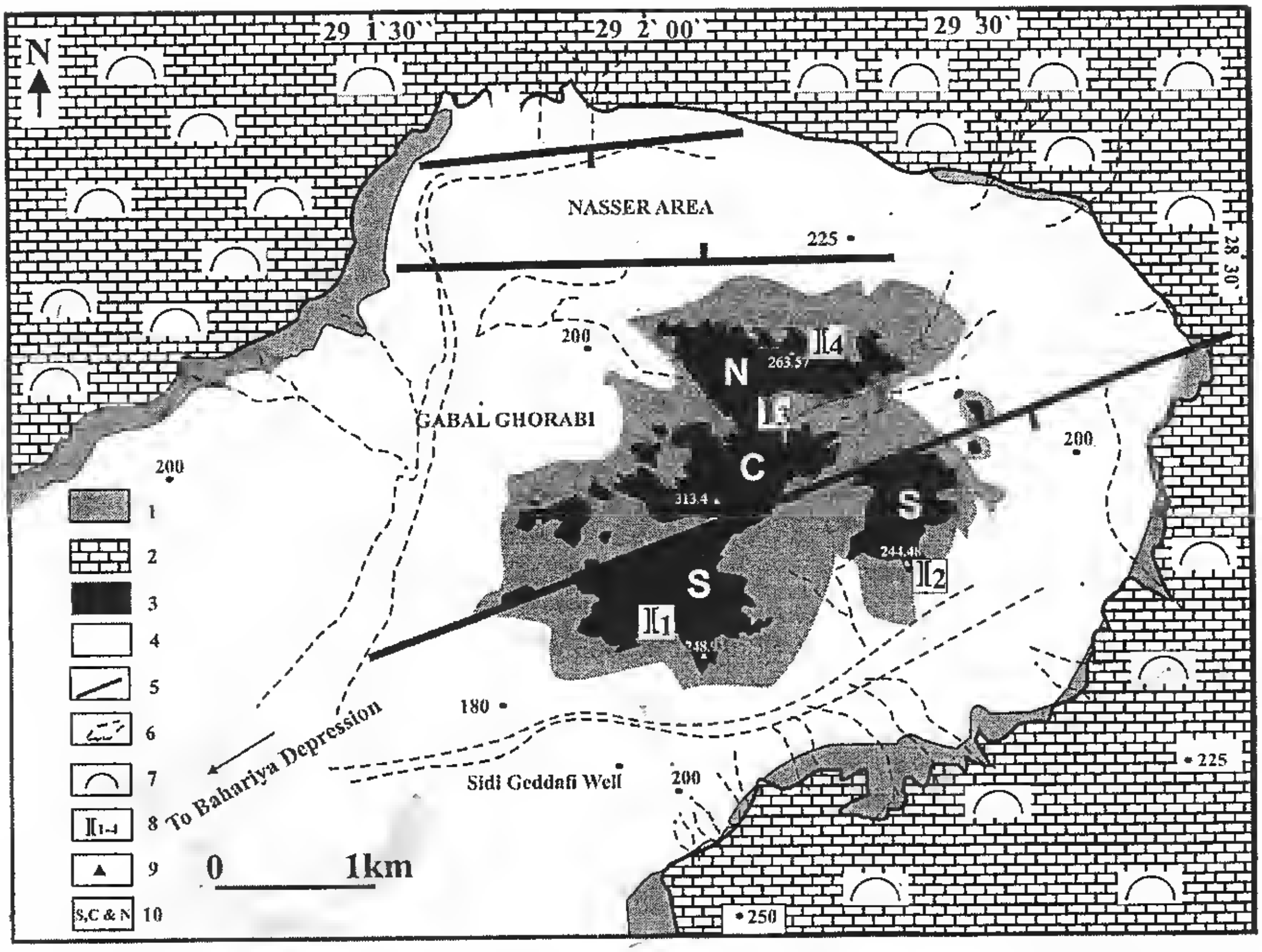


Fig.2. Simplified geological map of Ghorabi-Nasser area (based on the geological map of El Aref and Lotfy, 1989). 1) Clastic rocks of the Cenomanian Bahariya Formation; 2) Karstified limestones of the Eocene Naqb Formation; 3) Iron ore deposits; 4) Quaternary sediments; 5) Faults; 6) Drainage lines; 7) Cone karst; 8) Measured ironstone sections (1-4) and carbonate sections (5 and 6); 9) Triagulation points; 10) southern (S), central (C) and northern (N) sectors of Ghorabi mine area.

Gborahl ironstones are suhdlvlded hy El Aref *et al.* (2006) into two main shallowing-upward ironstone sequences, separated by an Intra- Eocene (paleokarst) unconformity (Fig. 3). Tbe lower lronstone sequence comprises four ironstone facies:

a) Lagoonal/tidal flat mud-ironstone facies that composed in the southern sector of Gabal Ghorahi of a lower dark violet to black manganese-rlcb bematltic burrow-mottled mud-ironstones grading upward into tblnly laminated to bedded hrlck red bematitic mud-lronstone. In the eastern part of this sector, this lower ironstone facles consists nf cbaracteristlc rhytbmlc alternations of thinly laminated kaolinltic and glauconitic mudstones and thinly laminated glauconitic mud-ironstones. This facies represents depositlon from suspension ln low energy water conditions,
b) Lagoonal fossiliferons lronstone facles dominated ln tbe soutbern sector of Gabal Gborahi mlne area and it is composed mainly of coarsening-upward cycles. This facies is deposited as a result of intermittent storm events,
c) A sballow subtidal-intertldal nummulitic-ooidal-oneoidal ironstone facies is dominated in tbe central sector and
d) A shallow subtidal nummulitic ironstone facles consisting of tbree sballowing-upward cycles. The sballow suhtidal-intertidal nummulltic-ooidal-oncoldal lronstone facies and the shallow subtidal nummulitic ironstone facies comprising perltidal facies association and developed on suhmarine swell during the shoaling-upward tendency and sea level fall.

Tbe upper ironstone sequence begins by tbe depositlon of shallow suhtidal green mudstone facies as a result of a new marine transgression followed by a peritidal ironstone sequence, wbich consists of tbree repeated shallowing-upward cycles (El Aref *et al.*, 2005). Tbe upper ironstone sequence is intensively laterltized and karstified and iron ore laterite and stratabound karst-related harite are formed.

## OBJECTIVES AND METHODOLOGY

The present work aims to elucidate the importance of biogenic activities in the formation of the genuine marine ironstones (El Aref, 1994; El Aref *et al.*, 1999; Helha *et al.*, 2001 and El Aref *et al.*, 2006) of Gahal Ghorahi mine area, El Bahariya Depression, Western Desert, Egypt. It also sheds light on the nature of the original precursor materials involved during tbe deposition of the recognized ironstone types. The different micro- and ultra-structures of the microbialite and the involved microhes are examined hy using transmitted and reflected light microscopy as well as scanning electron microscopy (SEM). The physical and hiochemical processes involved during the hiogenic accretion and hacterial metaholism as well as the related accumulation of the depositional and early diagenetic iron mineral phases are discussed and interpreted.

## MICROBIAL MORPHO-STRUCTURES OF GHORABI IRONSTONES (A CATALOGUE)

Based on the sedimentary structures, morphologies, microfahrics and facies associations, the microbialites can he suhdivided into three main morpho-types: 1) Ferruginous stromatolitic microhialites, 2) Ferriferous concentrically laminated mlcrohialites (ferriferous oncoids, micro-oncoids and ooids), and 3) Ferriferous peloids.

### I- Ferruginous stromatolitic microbialites (type: A, Fig. 4)

Tbis type of microhialites occupies tbe basal part of the stromatolitic ironstone facies in the central sector (Fig. 3) and forms local patcbes and bands within tbe lagoonal fossilifcrous ironstone facies of the southern sector of Gahal Ghorabi mine area. According to the shape of the stromatolitic lamlnae and tbeir outer morphology, this type can be suhdivided into two morpho-types; namely hiostromal (stratiform) stromatolitic huild-ups and digitate stromatolites.

- The hiostromal (stratlform) stromatolitic buildups (types: A1-A4, Fig. 4) constitute distinctly hedded, a hlanket-like biolamlnated stromatolitic buildup of limited extension and consists of bedding plane-orlented (stratiform) sets of stromatolitic laminae. Tbe stromatolitic laminae are laterally persistenco and exhibit even planar to slightly undulose and crenulated sbapes with low synoptic relief (Plate 1A & B). Flabellate tuft- and pinnacle-like microstructures of variable sizes and degrees of convexity may disrupt tbe lateral continuity of tbe stromatolltic laminae and contribute in tbe characteristic wavy appearance. The stromatolltlc laminae are almost uniform in thicknesses (isopachous), hut they may thicken and swell over substrate irregularities. Locally, the even planar stromatolitic laminae may sbow higbly crenulated and contorted shapes associated witb micro-scale faulting and brecclations (Plate 1C). Rounded to elongated ferriferous oncoids, ooids and peloids are commonly coexisted witbin the stromatolitic laminae. Irregular and lamlnoid voids form sponge pore fabrics related to intra-

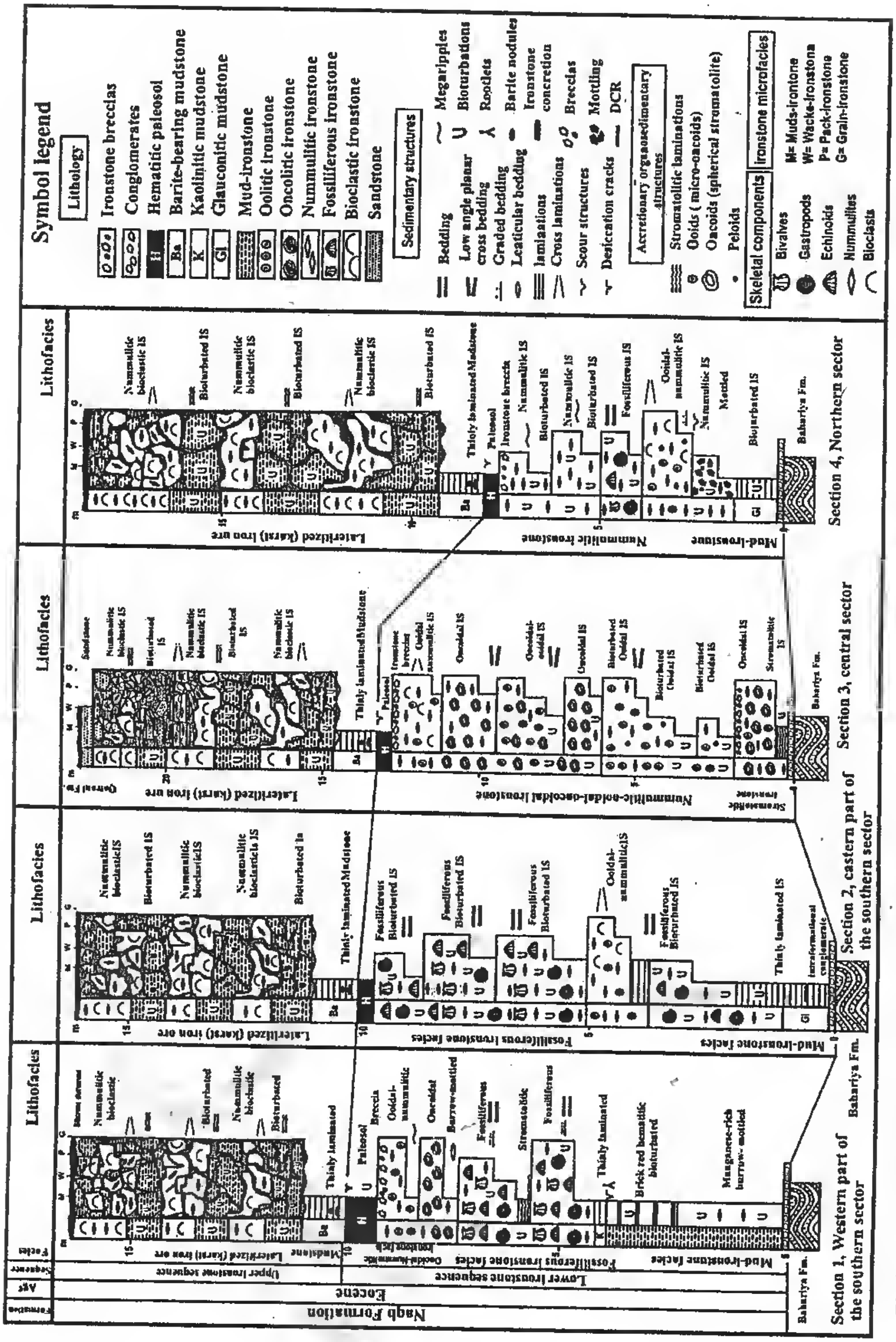


Fig.3. Stratigraphic sections showing the distribution of the different ironstone units and related facies in the different sectors of Gahal Ghorabi area (after El-Aref *et al.* 2006)

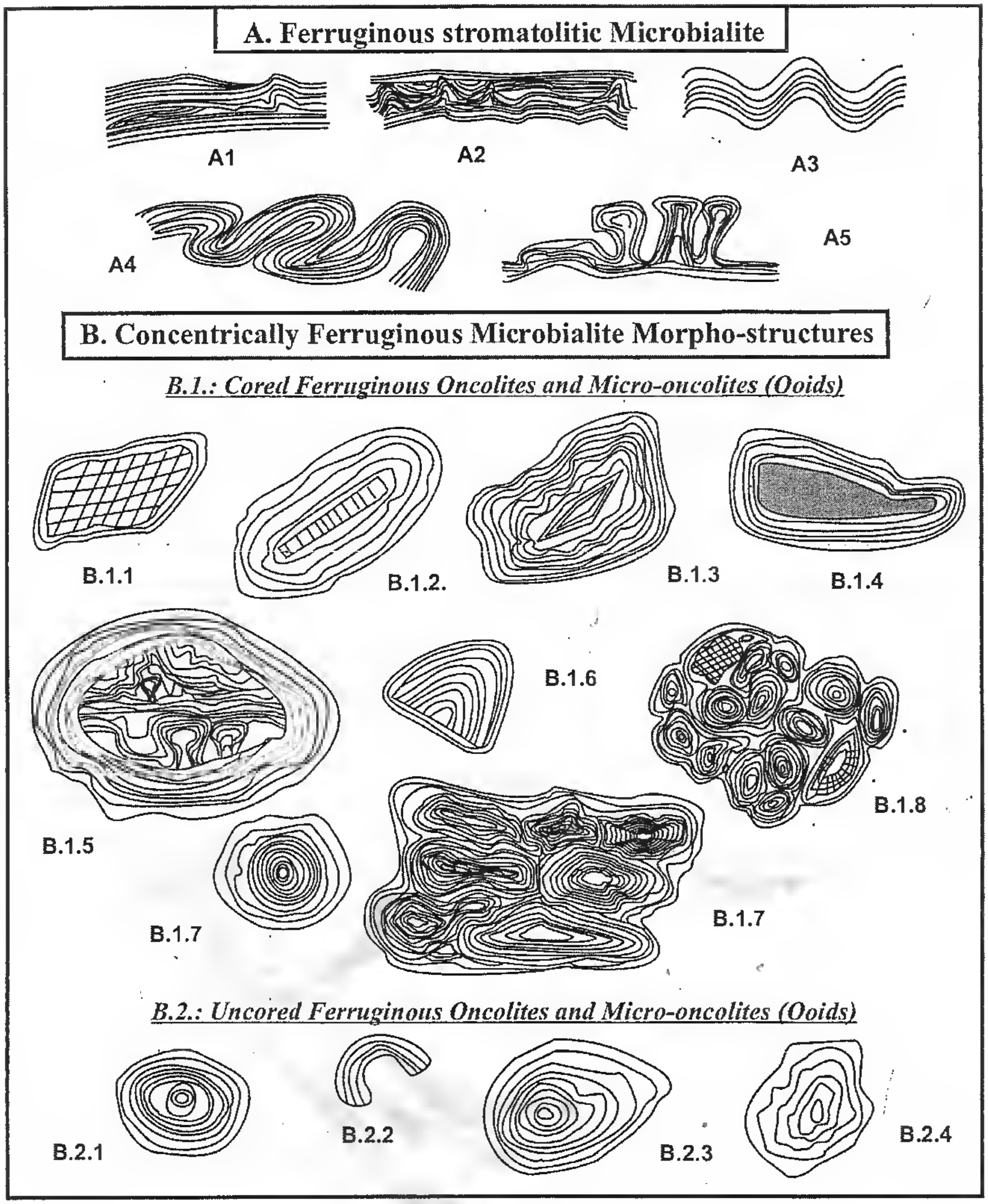


**Fig.4. Schematic illustrations of the recognized ferruginous microbialite morpho-structures**

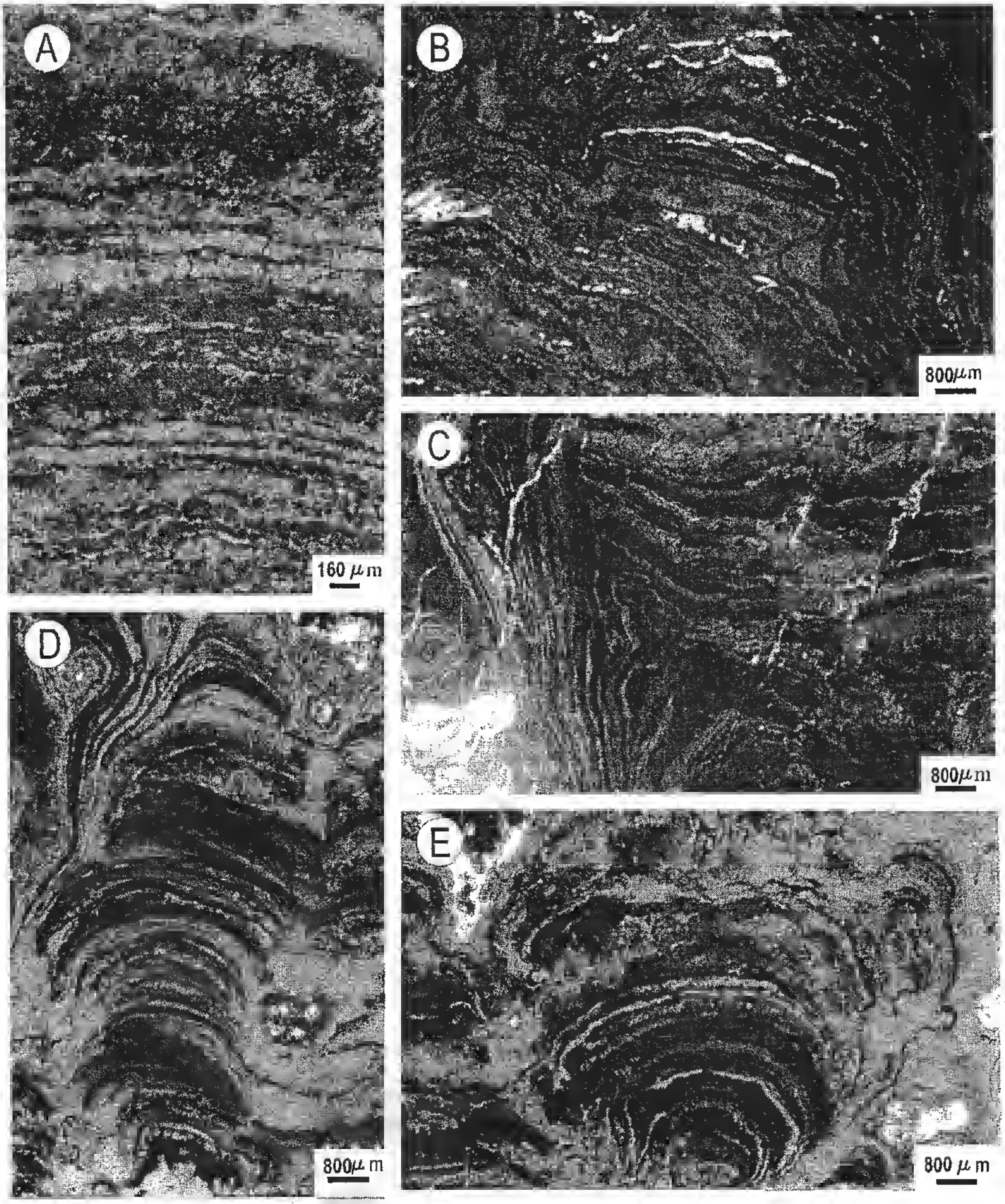


Plate 1. A) Planar "stratiform" stromatolite with even stromatolitic laminae of variable tones and thicknesses, PPL; B) Highly crenulated and non-isopachous stromatolitic laminae containing laminoid fenestrae (arrow), PPL; C) Highly deformed (microfolded and microfaulted) isopachous stromatolitic lamina, PPL; D) Digitate stromatolites with isolated or laterally linked vertically stacked micro-columns, PPL; E) Digitate stromatolites with isolated micro-dome or cobbage-like form consisting of amorphous iron oxyhydroxide laminae and brown organic-rich laminae with thin pyrolusite streaks, PPL.
PPL = Plane Polarized Light

sedimentary gases trapped beneath the organic-rich layers (Noffke *et al.*, 1997a &b; Gerdes *et al.*, 2000b). The coexistence of the different non-skeletal morpho-types (ferriferous oncoids, ooids and peloids) in one and the same unit of microbial sediments may reflect *in situ* formation as suggested by Cornell *et al.* (1992). The development of ferriferous ooids and oncoids within the same microbial mat is suggested by the similarity of the mineralized fossil microbial structures of both coated grains and the surrounding matrix (Dahanayake and Krumbein, 1986). Biogenic burrowing organisms together with the diagenetic modifications may share in the deformation of these stromatolitic laminae and led to the separation of microbial mat chips, which are associated with the main body of the stromatolitic buildup. The biostromes are commonly developed under low energy conditions in a low tidal range. Reid and Browne (1991) reported smooth mat from intertidal environment. Smooth mats are common in tide dominated settings of low to moderate energy (Gerdes and Krumbein, 1994).

- The digitate stromatolites (Aitken, 1967) form small-scale surface irregularities on the uppermost surface of the planar (stratiform) type (type. A5, Fig.4). These irregularities grew into branched finger-like forms or small-scale columns and domes consisting of vertically stacked hemisperoids or club-like heads of low relief. The individual fingers are separated by amorphous iron oxyhydroxides and may coalesce upward by the development of lateral linkage into more compound domal and columnar types (Plate 1D & E). Few rounded to elongated ferriferous ooids and peloids are observed within the inter-domal and inter-columnar areas. The stromatolitic laminae show variable colour intensities ranging from egg-yellow amorphous Iron oxyhydroxide laminae to dark brown goethitic laminae. Thin continuous and/or discontinuous streaks of Mn oxyhydroxides are aligned parallel to or cutting through the stromatolitic laminae.

2- Ferriferous Concentrically Laminated Microbialites (type: B, Fig. 4)
These microbialites include ferriferous oncoids, micro-oncoids and ooids that may or may not associated together within the same environment and can be differentiated according to their sizes and internal structures as follows:

Ferriferous oncoids are defined as grains of more than 2 mm in diameter and their cortical laminae are often wavy and usually discontinuous (ironstone glossary-Young, 1989). The oncoids are also defined as laminated biosedimentary structures formed by microscopic bacteria and belonging to stromatolites (Flügel 1982). Ferriferous micro-oncoids are defined as grains of less than 2 mm in diameter with irregular (wavy and discontinuous) concentric structures (Dahanayake and Krumbein, 1986).

Ferriferous ooids are defined as grains of less than 2 mm in diameter having regular concentric cortical laminae and spheroidal to ellipsoidal shapes (ironstone glossary-Young, 1989). Dahanayake and Krumbein (1986) advocated biogenic origin for these grains as they are associated with oncoids and microbial mat.

According to the internal structures and the outer morphology, the concentrically laminated microbialites of the study ironstones are subdivided into two main types: a) cored ferriferous oncoids and micro-oncuids (ooids), and b) uncured ferriferous oncoids and micro-oncoids (ooids).

A- Cored ferriferous oncoids and micro-oncoids (ooids), (type B1, Fig. 4)
These ferriferous coated grains are of variable sizes and shapes and their cortical laminae (sheath) may encrust a variety of cores. The cores (nuclei) of these grains may include: a) ferruginized and/or silicified skeletal particles (microbored foraminiferal tests and bioclasts of echinoderm plates, echinoid spines, bivalves and skeletal algae), or b) non-skeletal particles (ferruginous massive angular mud-ironstone clasts, stromatolitic chips and fragments, ferriferous peloids, ferriferous ooids and groups of ooids).

1. The ferriferous oncoids and micro-oncoids (ooids) with cores of ferruginized and/or silicified skeletal particles are often associated with the stromatolitic (microbial) ironstone facies and with the upper part of the nummulitic-ooidal-oncoidal Ironstone facies (types. B1.1, B1.2 and B1.3 of Fig. 4). The oncoids that are associated with the stromatolitic ironstones are of variable sizes and shapes and have vaguely fitted boundaries and highly irregular (amoeboidal) outlines. The shapes of these ferriferous oncoids are largely determined by the kind and shape of the nucleus. The oncoid cortical laminae are thin, well-developed and concentrically to semi-concentrically encrust ferruginized foraminiferal tests or algal plates and have thin even, slightly wavy and highly crenulated morphology. The cortical laminae thicken and swell over the irregularities of their central cores and may overlap each others. The oncoid cortical laminae may be disrupted by

desiccation and biogenic burrowing effects, which led to the separation of segments of oncoid cortices to be cores of further oncoid formation. These concentrically laminated grains are generated in relatively calm conditions prevalent within the microbial mat (Dahanayake and Krumhein, 1986). The ferriferous oncoids associated with storm beds of nummulitic-ooidal-oncoidal ironstone facies are of the same shapes, sizes and internal structures. These oncoids have rounded and spheroidal to ellipsoidal shapes. Their nuclei include partially to completely ferruginized and/or silicified foraminiferal tests and bioclasts of echinoderm plates, echinoid spines, bivalves and skeletal algae. The contact between the cores and the surrounding cortices is slightly corroded aided by the effect of endolithic microorganisms. The corroded outlines of the cores led to the development of pronounced embayments and bosses, where the cortical laminae thicken into embayments and are thin or absent over the bosses. There is a remarkable reverse relation between the size of the core and the surrounding cortical laminae. Large-sized cores are coated by thin irregular rind or mineralized film of micrometric thick egg-yellow amorphous iron oxyhydroxides forming superficial oncoids and micro-oncoids (Plate 2A & B). Small cores are coated by thick undifferentiated or poorly developed concentric cortical laminae of smooth rounded to slightly wavy and crinkled shapes (Plate 2C & D); sometimes they are alternated with laminae of club-shaped micro-stromatolitic and knobby shapes. Few oncoids exhibit a polarity in the development of their cortical laminae, being thicker at the edges or corners of the nuclei.

2. The ferriferous oncoids and micro-oncoids (ooids) are cored by non-skeletal particles (types, B.1.4 to B.1.9, Fig.4). The cortical laminae of these oncoids are developed on cores of massive angular mud-ironstone clasts (type. B1.4, Fig. 4), stromatolitic mat chips and fragments (type. B1.5, Fig. 4, Plate 2E) or they can envelope intact and/or segments of ferriferous ooids, peloids (types. B1.6 and B1.7, Fig. 4) and groups of ooids and oncoids (types B1.8 and B1.9 of Fig.4 and Pl. 2F). The majority of these oncoids are of rounded to sub-rounded spheroidal shapes, few types are of ellipsoidal shape. The oncoid cortical laminae have a complicated growth history, expressed by the development of multiphase encrustations or shells of different stromatolitic morphologies. They are closely punctuated with abrasional events indicating short-lived micro-unconformities and may reflect the role of tidal and/or storm currents in the reworking of the ferriferous coated grains during their formation (Plate 3A). Each of these encrustations has smooth to slightly wavy morphology and they are usually thickened over the rough surfaces of their cores. The cortical laminae often overlap with each others and may incorporate ferriferous peloids, ooids and ferruginized skeletal grains during their development. The oncoidal encrustations may or may not lack its continuity around their cores. They may truncate with each others or separated disconformably by thin irregular blood red to black hematitic lamina. Few oncoids appears to be developed as a composite type, where thin to thick even cortical laminae envelop a group of rounded and ellipsoidal ferriferous ooids, peloids and less frequent ferruginized skeletal grains in a form similar to the "ooid bag". Foraminiferal tests may alternate with the true oncoid cortical laminae forming hyprid coated grains similar to those described by Burkhalter (1995). The microbial (stromatolitic) mat chips are suggested to be derived from their parent microbial mat by water agitation during tidal and/or storm waves and currents (Gerdes and Krumbein, 1987). The rounded nature of these chips is often related to transportation and deposition under agitated conditions.

B- Uncored ferriferous oncoids and micro-oncoids (ooids), (type: B2, Fig. 4).
These ferriferous oncoids and micro-oncoids (ooids) do not possess obvious cores and they have various sizes and shapes. They are of spheroidal to ellipsoidal shapes (type: B2.1, Fig. 4, Plate 3B) with few types having plastically deformed or spastolithic forms (type: B2.2, Fig. 4). Internally, the laminae are continuous or discontinuous, isopachous and smooth to slightly wavy in shape. Few ferriferous ooids and oncoids of this type are thoroughly bioturbated and their internal microstructures became less distinct. Some of which have poorly defined boundaries between their laminae and may leave false or pseudo-cores at their centers. Some oncoids and ooids have laminae made up entirely of rounded coccoid cyanobacterial cells alternated with layers of egg-yellow to brown amorphous iron oxyhydroxides. Few ferriferous oncoids and micro-oncoids have spheroidal to highly irregular bumpy, nipple-like, box and colloform outlines. The internal structures of these grains consist of convex outward discontinuous, wavy to slightly crenulated laminae (types: B2.3 and B2.4, Fig. 4, Plate 3C). In large oncoids, the cortical laminae are non-isopachous and grade from slightly to highly crenulated, giving rise to knobby, juxtaposed club-shaped or digitate micro-stromatolitic structures. Some of these oncoid cortical laminae incorporated small ooids, peloids and/or ooid fragments. The laminae commonly exhibit overlapping and truncation patterns (Plate 3D).

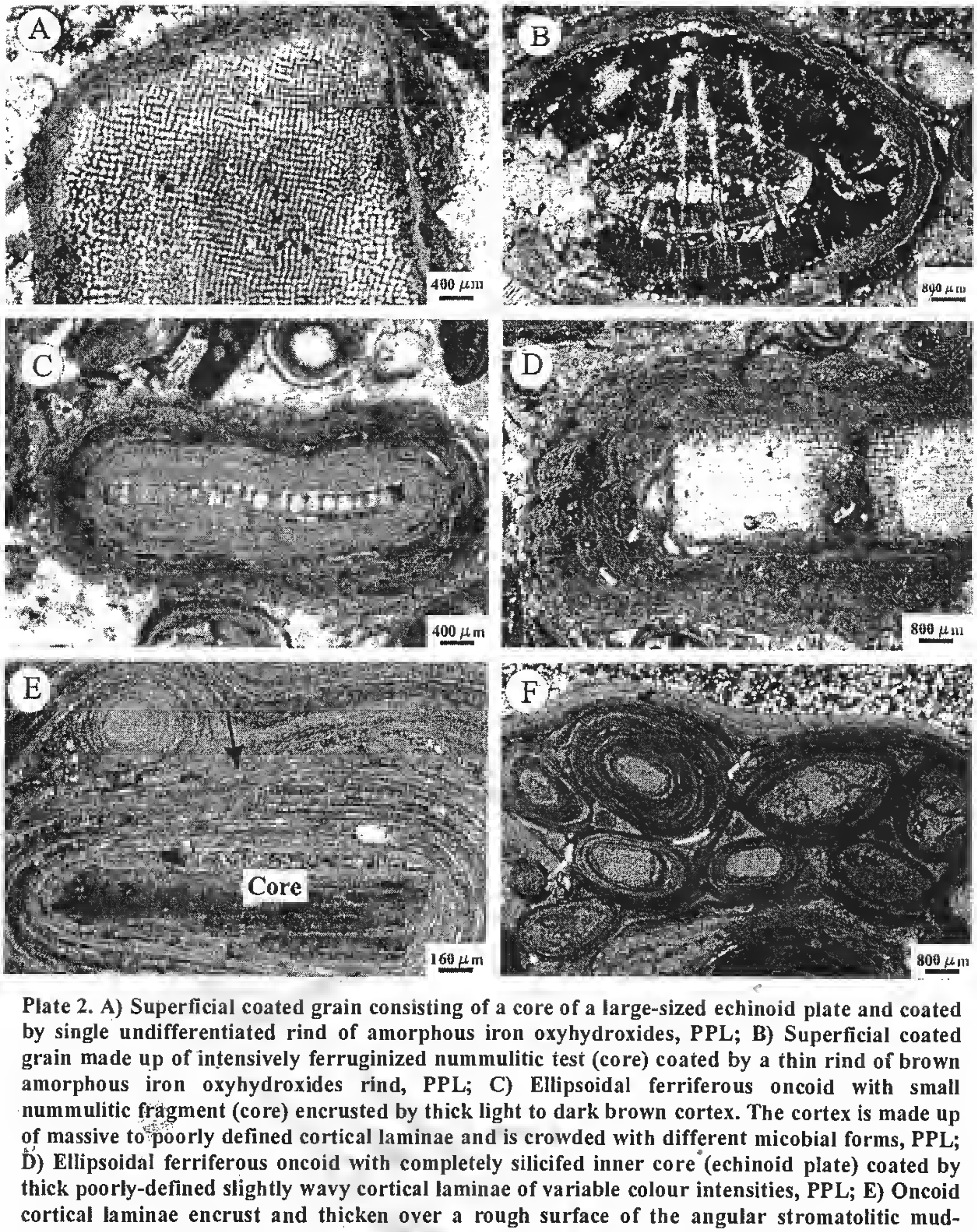


Plate 2. A) Superficial coated grain consisting of a core of a large-sized echinoid plate and coated by single undifferentiated rind of amorphous iron oxyhydroxides, PPL; B) Superficial coated grain made up of intensively ferruginized nummulitic test (core) coated by a thin rind of brown amorphous iron oxyhydroxides rind, PPL; C) Ellipsoidal ferriferous oncoid with small nummulitic fragment (core) encrusted by thick light to dark brown cortex. The cortex is made up of massive to poorly defined cortical laminae and is crowded with different micobial forms, PPL; D) Ellipsoidal ferriferous oncoid with completely silicifed inner core (echinoid plate) coated by thick poorly-defined slightly wavy cortical laminae of variable colour intensities, PPL; E) Oncoid cortical laminae encrust and thicken over a rough surface of the angular stromatolitic mud-ironstone fragment (core). The cortical laminae overlap and truncate with each other (arrow) and incorporate rounded ferriferous ooid, PPL; F) Aggregate grain consists of group of ellipsoidal ferriferous ooids surrounded by thin cortical laminae similar to the ooid bag, PPL.
PPL. = Plane Polarized Light

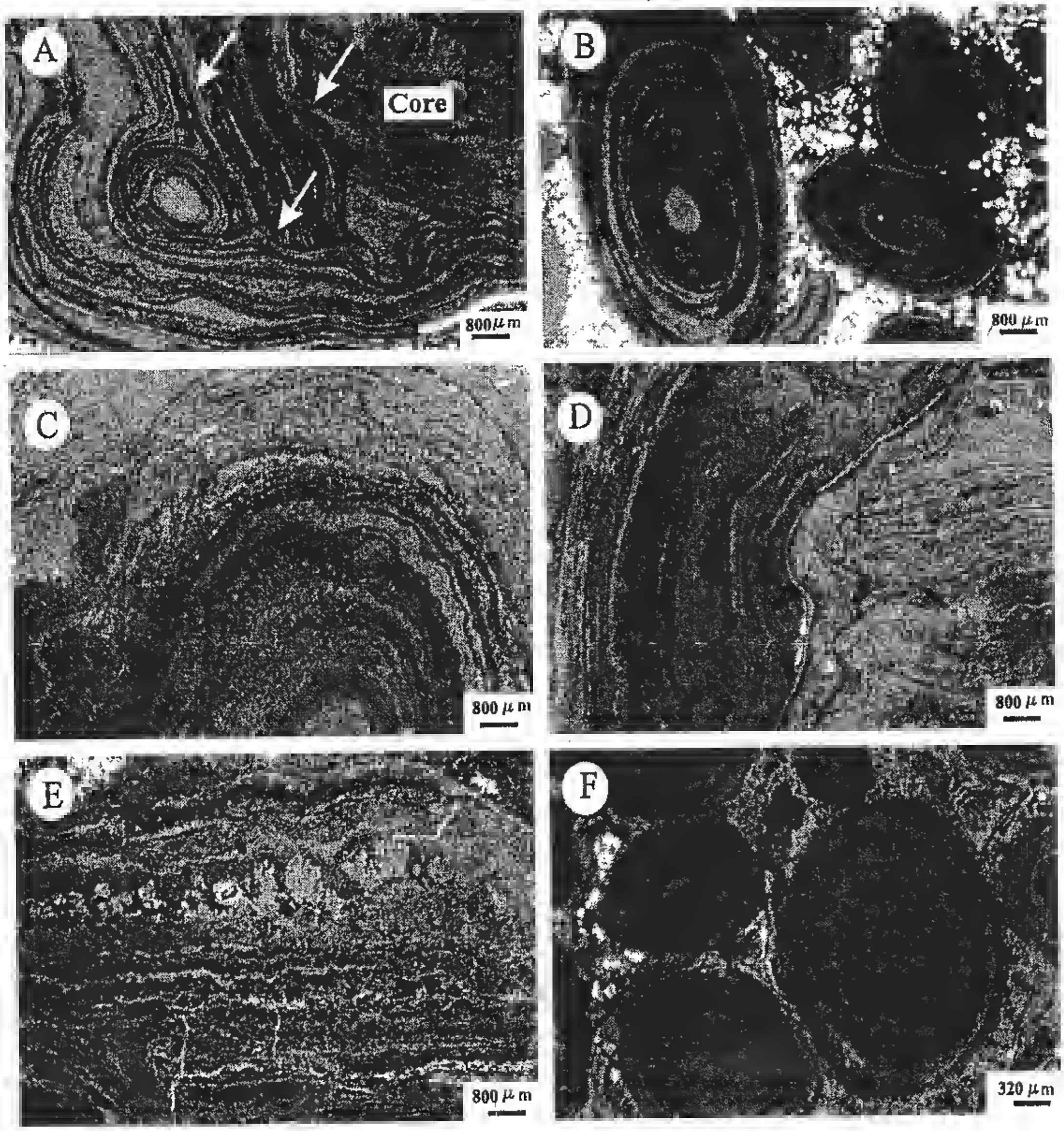


Plate 3. A) A part of large ferriferous oncoid with inner core made up of stromatolitic fragment and outer multiphase encrustations separated by erosional surfaces (arrows). The cortical laminae incorporate rounded ferriferous ooid, PPL; B) Uncored rounded ellipsoidal ferriferous oncoids and ooids with poorly defined boundaries between the laminae, PPL; C) Slightly wavy oncoial laminae showing alternated couplets of egg-yellow amorphous iron oxyhydroxide laminae and light to dark brown organic-rich laminae made up entirely of coccoid and erect filamentous cyanobacteria, PPL; D) A part of large-sized ferriferous oncoid showing overlapped cortical laminae with different colours and mineral composition, PPL; E) Part of ferriferous oncoidal cortex exhibits laminae with shrub-like morphology alternate with massive planar laminae, PPL; F) *In-situ* formed rounded ferriferous peloids or pseudo-ooids with poorly defined laminae, PPL.
PPL = Plane Polarized Light

The close-up inspection of the oncoid cortical laminae may reveal that these laminae are massive, spongious or thrombolitic in shape. Few oncoids contain irregular hemispherical intercortical voids resembling spongy oncoids of Aitken (1967) which are related to encrusting tubular organisms (Dreesen, 1989). Some oncoid cortical laminae have a shrub-like morphology (Plate 3E) and could be termed "bacterial oncoids" similar to those described by Folk and Chafetz (1983). The shrub-like morphology of these cortical laminae is interpreted as nucleation around bacterial clumps (Chafetz and Guidry, 1999). Few large ferriferous oncoids are built up on a completely ferruginized cell colony of rounded cells. The ferriferous oncoids and micro-oncoids (ooids) appear to be neither allochems sensu Folk (1959, 1962), but authigenically-formed biogenic grains according to the conclusion of Dahanayake and Krumbein (1986). The shallow-water conditions in shallow lagoonal environment surrounded by tidal flats would be the ideal sites for the *in situ* growth of the ferriferous ooids and oncoids in microbial mats (Dahanayake and Krumbein, 1986).

3- Ferriferous peloids

These are internally massive spheroidal to ellipsoidal ferriferous grains and they occur as free constituents or form the cores of the ferriferous ooids and oncoids. They have the same shape and size of the ferriferous ooids and always associated with ferriferous ooids and oncoids (Plate 3F). These ferriferous peloids can be considered as pseudo-ooids (Young, 1989). Few peloids appear to be developed as a result of complete hematitization and obliteration of the internal structures of the skeletal particles. Less frequent intraclasts are often associated with these ferriferous peloids and consist of angular to subangular mud-ironstone rock fragments with few particles being derived from ferriferous ooids and oncoids. These ferriferous peloids and intraclsts are formed of yellow brown amorphous iron oxyhydroxides mixed with ultra-fine poorly crystalline ferrihydrite crystallites as well as goethite and hematite.

## MICROBES AND THE ASSOCIATED SEDIMENTS

The microbialites are characterized by the intimate interaction between the microbial activity, the colonized surfaces and the surrounding environments (Stolz, 2000). The microbial communities, responsible for the microbialite growth, are all the microscopic organisms, which encompass bacteria (including cyanobacteria), fungi, small algae and protozoans (Brock *et al.*, 1994; Ehrlich, 1996; Nealson, 1997; Riding and Awramik, 2000). Benthic cyanobacteria are photoautotrophic microorganisms (previously termed blue-green algae, blue-green bacteria, and cyanophytes). They represent the most important group of microbes from the sedimentological point of view because they live in almost every habitat (Knoll and Bauld, 1989) including the coastal peritidal ecosystem. Two cyanobacterial morphotypes are recorded within the stromatolitic laminae of the biolaminated (biostromal) buildup as well as the cores and cortex of the ferriferous oncoids and micro-oncoids (ooids), these are: a) filamentous types consist of erect ensheathed or sheathless bundled or single trichomes (elongated cell chains). The cyanobacterial filaments are attached mainly to rigid substrates that may involve skeletal particles and intraclasts (Plate 4A), and b) coccoidal types consist of spherical to ovoid-shaped cells. These cells are arranged together within the cortical laminae (Plate 4B) or they in a random and/or regular dispersal and colonial aggregations (Plate 4C & D). These are the most prominent types that are present with or without the filamentous types and are most probably attached to soft substrates, i.e., iron oxyhydroxides laminae. The ultra-structures of the cyanobacterial forms are maintained by using the high magnifications of the transmitted light microscopy, reflected light microscopy and SEM micrographs. Under SEM, the spherical to subspherical coccoidal cyanobacterial bodies are randomly distributed or closely packed in grape-like clusters and associated with straight to gently curved filaments (Plate 4E & F). The tiniest spherical bodies whose natural naked size is 0.2-1 μm are most probably similar to nannobacteria (dwarfed forms, Plate 4C) described by Folk (2001). Guo and Riding (1994) reported similar spherical bodies (bacteriform bodies) and interpreted them as remains of bacteria.

### Mineralogy And Microscopic Observations

Microscopically, the stromatolitic and concentrically laminated microbialites have the same mineral composition and internal structure. They are formed of superposed doublets made up of light sediment-rich laminae and dark organic-rich laminae (Plate 1A). The light organic-poor laminae consist of egg-yellow amorphous iron oxyhydroxides mixed with cryptocrystalline ferrihydrite crystallites and remains of glauconitic clays as well as earthy and authigenic cryptocrystalline kaolinite. The dark brown organic-rich laminae consist of microbial biomass embedded in iron-rich glauconitic clays and amorphous iron oxyhydroxides. The microbial biomass consists mainly of iron encrusted rounded to rod-shape coccoid cyanobacterial cells arranged side by side or in colonies. Also, the filamentous cyanobacteria are attached

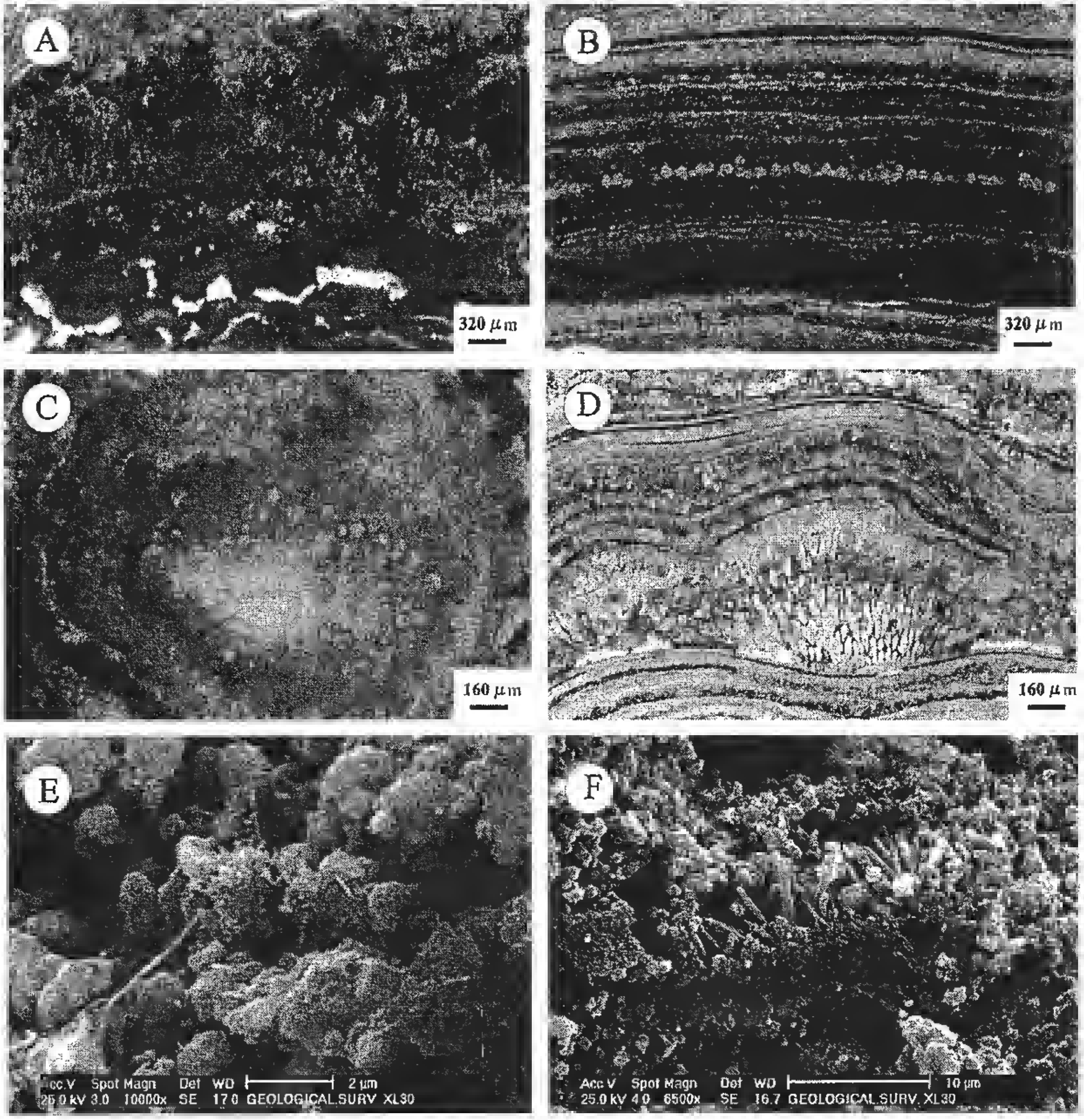


Plate 4. A) Erect single and bundled ferruginized cyanobacterial filaments aligned perpendicularly to the oncoid cortical laminae, PPL;. B) Thinly laminated even oncoid cortex consisting of egg-yellow amorphous iron oxyhydroxides and dark brown organic-rich laminae. Note that few laminae consist entirely of closely spaced coccoid cyanobacterial cells (arrow), PPL; C) Rounded single and bilobed coccoid cyanobacterial cells embedded in glauconitic clays and egg-yellow and brown amorphous iron oxyhydroxides matrix, PPL; D) Intensively mineralized (hematitized) rounded, tubular and branching microbial structures oriented perpendicularly to the stromatolitic laminae and alternated with glauconitic clayey laminae, R.L.; E) Scanning electron photomicrograph (SEM) showing the ferrihydrite aggregates consisting of spherical bacterial bodies and forming grape-like clusters or mammillated encrustations; F) Scanning electron micrograph (SEM) showing the isolated minute spherical bacterial bodies (nannobacteria?) and grape-like clusters adhere to the surface of the cyanobacterial filaments that attached to the slimy muddy substrate.

PPL = Plane Polarized Light R. L. = Reflected Light

perpendicularly to the sediment-ricb laminae. Tbin discontinuous pyrolusite streaks are aligned parallel to tbe main stromotolitic laminations and associated with the green glauconitic clay laminae. The mineral composition of tbese microbialites represents the primary depositional (precursor) materials including unstable egg-yellow amorphous iron oxybydroxides, cryptocrystalline ferribydrite crystallites and traces of yellowisb green glauconitic and kaolinitic clays. Tbe bacterial cells may sbow weak degradation during diagenesis, while otbers are easily destroyed by strong mineralization (Gehring, 1986 a). Tbe mineralized bacterial cells are partially to completely encrusted by amorphous iron oxybydroxides and ferrihydrite witb very low concentrations of Ti and Mn. In microbial mats, individual hacterial cells or micro-colonies were frequently surrounded by amorpbous iron-ricb capsular materiols or fine-grained iron-rich spheroids (Konbauser and Ferris, 1996). Extracellular grains of acicular goethite were identified on bacterial surfaces.

## MICROBIALITES ACCRETION MECHANISM AND DEPOSITION OF IRON COMPOUNDS

Tbe study marine ironstone succession was deposited in sballow subtidal-intertidal lagoonal and peritidal environments of oxygenated, normal to brackisb water and witbin a neutral to alkaline medium. Tbese environments are considered as an ideal site for tbe development of various microbial structures. Sucb structures are deposited from suspensions under calm water conditions in areas of low tidal influences, low or negligible sedimentation rate ond interrupted by storm events of bigh bydrodynamic forces (El Aref *et al.* 2006). Tbe proposed accretion mecbanism of the microbial structures depends on two main factors. Tbe first one is what tbe nature of tbe precipitated materials availahle during the microbiolites growth. The second factor is what tbe role of micro-organisms during the precipitation and diagenesis of the iron-rich colloidal precipitates.

The abundont distribution of the recognized organo-sedimentary structures reveals that they developed within shallow lagoons ond small ponds surrounded by tidal flats. The sballow sea bottom is colonized by benthic microbiota, probably Fe-depositing bentbic bacteria and cyanobacteria, living at tbe water-sediment interface, whicb affect fluid flow dynamics and structure formation. These microbes flourish in low-energy water condition and envelope the mineral grains of tbe depositional surfaces forming organic coatings or "biofilm". Tbe biofilm is defined as sub-millimetric veneers of bacterial populations and communities embedded in tbeir mucous extracellular polymeric substances (EPS), attacbed to tbe substrates in aquatic environments (Decbo, 2000; Paterson and Black, 2000 and Stolz, 2000). The microbes produce copious amounts of EPS, whicb are essential for the formotion of microbial deposits. The importonce of tbe EPS is in the accretion mechonism and deposition of the iron compounds can be expressed by the following ecological functions:

1. EPS forms an adbesive muciloge that attaches microbes firmly to substrates and surfaces of depositional grains (Decho, 1990 and Stolz, 2000),
2. EPS provides pbysical and chemical protection against the stress factors affecting the microbes,
3. EPS aids in nutrient transport and absorption (Cbristensen and Cbaracklis, 1990 and Decho, 1990),
4. EPS facilitates metabolic interaction,
5. EPS acts as diffusion barrier and adsorbent (Lawrence *et al.*, 1994), and
6. EPS leads to sediment trapping and mineral precipitation.

At sites of such fovourable ecological conditions, the erect cyonobacterial filaments cause trapping of tbe very fine-grained sedimentary particles held in iron-ricb suspensions by tidal current througb eitber simple pbysical blockage (baffling) of particle movement or biocbemical adsorption on and in EPS to become agglutinated and stabilized against erosion (Noffke *et al.*, 1997 a & b and Gerdes *et al.*, 2000 a & b).

In tbe oxygenated sea water, tbe soluble ferrous form of iron ($Fe^{2+}$) is stabilized at low pH and transported into an oxygenated envlroument as colloids (Wells *et al.*, 1995) or form organic complexes (Ehrlicb, 1990). It spontaneously reacts with dissolved oxygen and oxidized to an insoluble ferric form ($Fe^{3+}$) at circum-neutral pH (~ 7-8) to precipitate rapidly (abiotically) as iron oxyhydroxides (Byrne and Kester, 1976) on available nucleation sites. At the 7-8 pH, tbe anionic groups of tbe cells easily scavenge ferric iron from tbe surrounding waters (Juniper and Tebo, 1995). Bacteria act as sucb nucleation sites or stabilizing agents and simply adsorb tbe metastable pbases of cationic colloidal iron oxybydroxides on tbeir anionic cell surfaces (Konbauser *et al.*, 1993, 1994a; Tebo, 1995 and Fortin *et al.*, 1997). Tbe bacterial cells initially sbowed the nucleotion of small dense, Iron-ricb aggregates on tbeir outer surfoces tbat may grow into granular and spberoidal crystallites. Tbus, hacterial cells can precipitate a voriety of Iron minerols (bocterial biomincrals) and usually the biogenic minerals bave cbemical compositions similar to tbose produced by abiotic (inorganic) precipitation (Konhauser, 1998). These iron minerals can be formed by

hacterial processes (Ghiorse and Ehrlich, 1992; Mann *et al.*, 1992 and Brown *et al.*, 1999) like bacterial carbonate biominerals tbat form micrometric thick carbonate spheres, rods, dumbbells and rosettes (Chafetz and Buczynski, 1992). Over a short period of time, the microhial mat can become completely encrusted with amorphous iron oxyhydroxides ond ferribydrite as a biological surface catalysis of the biofilm accelerates the rate of iron mineral precipitation (Konbauser, 1997 and 1998). In response to zero or low rate of sedimentation, another biofilm continues to grow as a new hlomass layer. During the next burial events, dead biomass ls left hehind as organic-rich lamlnae. The trapping process is carried out witb low-rate sedimentation and goes hand-in-hand with tbe dual process of hinding. Tbis process results in sediment-rich and organic-rich hiolaminated deposits (Gerdes and Krumhein, 1987) with significant smootb organic layers with little surface topography.

The ooidal and oncoidal ironstones of Gahal Gborahi mine area are suggested to he developed during continuous construction of concentric laminations of the ferriferous oncoids and ooids hy hiofilm attachment to solid skeletal or non-skeletal nuclei that are associated microhial mats. The skeletal particles include foraminiferal tests and hioclastic dehris of macro-fauna are hrougbt to tbe area of deposition durlng tbe storm event and oct as suhstrates for the cortex development. The microhial growth and EPS production occur ln calm water conditions, prohahly during the inter-storm periods and result ln substantial thlcknesses of organic layers around nuclei. The hacterial cells and their EPS maintain chemical changes in the medlum surrounding solid-liquid interface. These hiologlcally induced changes affect the microenvironment ond the accumulation of amorphous iron oxyhydroxides on the hiofilms occurs, which contrihutes to the next cortical layers in the ferriferous oolds and oncoids. Repeated direct or episodlc entrapment and precipitation of iron-rich suhstances from colloidal solution or suspension may he the main controlling process in maintaining the growth of hlofilm and determining the concentric lamination of the ferriferous ooids and oncoids. The benthic hacteria and cyanohacteria consume the dissolved oxygen in the interstitial pore water to decompose the organic matter involved in the iron oxyhydroxide precipitates. These processes take place during the early diagenesis, where the environment is changed from the oxic to post-oxic condition.

The foilowing criteria argue for tbe *in situ* biogenic origin of the ferriferous ooids and oncoids of Gahal Ghorahi ironstones. These criteria comprise:

1. Tbe lack of true nuclei in case of uncored ferriferous ooids and oncoids and in many cases the cortical laminae are only characterized by dark-ligbt gradations.
2. Tbe ferriferous ooids and oncoids have even to wavy and overlapping nature, sometimes with club-shaped and knohhy micro-stromatolitlc cortical laminae. These features may strengtben the biogenic role in the formation of the ferriferous ooids and oncoids.
3. In few cored ferriferous ooids and oncoids, there is no clear separation of the nuclei from the innermost cortical laminae.
4. Some ferriferous ooids and oncoids have cores made up of hacterial cell colony.
5. The occurrence of coccoid and filamentous cyanohacterial celis in the cortlces of the ferriferous ooids and oncoids clearly indicate *ln situ* origin (Gerdes *et al.*, 1994).
6. The vaguely polygonal fitting of the amoehoidal cortical laminae of the ferriferous ooids and oncoids associated with the stromatolitic microhialites.
7. The difference of the thicknesses of organic-rich laminae around a nucleus clearly indicates differences in the time available for biofilm to grow and reproduce.
8. Some ooids contain inter-cortical irregular voids, which are most prohahly considered as gas bubhles, growing during tbe development of the cortical laminae hy the bacterial decomposition and microhial fermentation of organlc matter.
9. Tbe ferriferous ooids, oncoids as well as tbe enclosing matrix are bioturhated and contain traces of ferruginized microhial forms.
10. Tbe bazy and corrosive contacts hetween the core (skeletal particle) and the surrounding cortical laminae.
11. The ferriferous ooids and oncoids have o reverse relationship hetween the thickness of the cores and the surrounding cortices.
12. The majority of the ferriferous ooids and oncoids arc characterized hy discontlnuous and non isopachous cortical laminae, which suggests that the growth is not uniform in all directions.
13. The amalgamation of different non-skeletal particles witbin the same grain simllar to the "ooid hag".

The ferriferous peloids have rounded or irregular forms and are associated with the ferriferous ooids and oncoids and almost has the same *in situ* biogenic origin. The ferriferous peloids are formed either by the hocterial activity or through the diagenetic processes. The interaction hetween the microhial communlties

and the associated sediments result in separation of internally massive regular and/or irregular areas forming *in situ* ferriferous peloids. Chafetz (1986) discuss the role of the bacterial activities in the formation of peloids. Pickard (1992) considered the *in situ* origin of the peloidal fabrics within the microbial mat either by the direct microbial precipitation within the microbial mat or indirectly via diagenetic decomposition of the organic matter associated with the microbial mat.

## MICROBES AND DIAGENESIS

The role of microbes is not only during the precipitation of iron-rich colloidal suspension but also extends into the early diagenetic processes. As soon as the iron-rich clays are deposited, they become easily lithified, and slightly recrystallized into amorphous iron oxyhydroxides and/or poorly crystalline ferrihydrite aggragates. The scanning electron microscope photomicrographs reveal that the main habit of the ferrihydrites is isolated subspherical and/or dense clustered and grape-like aggregates. The morphology of these ferrihydrite aggregates are similar to the modern ferrihyrite precipitates described by Cornell and Schwertmann (1996) and Casanova *et al.*(1999) and the calcium carbonate precipitates described by Chafetz and Buczynski (1992), Folk (1993) and Casanova *et al.* (1999). These morphological forms are commonly liked to direct or indirect bacterial activity, where the bacterial cells act as nuclei for the iron precipitation. The small, spherical particles of the ferrihydrites often pack together to form aggregates (> 0.1lm) across. Due to aggregation of particles, ferrihydrite aggregates are microporous (interparticle porosity) and the pore spaces represent passways, which facilitate the movement of the interstitial interparticle fluids during the early stages of diagenesis.

The early diagenetic processes can be described as post-oxic (weakly reducing) environment and include: 1- Organic matter degradation and matrix pelletization and oolitization, and 2- Diagenetic ferruginization (replacement) of the calcareous skeletal particles.

### 1) Organic matter degradation and matrix pelletization and oolitization

During the early stages of diagenetic changes, the degradation of organic matter by aerobic bacteria and cyanobacteria, colonizing the sediment surface, results in a consumption of all the dissolved oxygen of the interstitial pore fluids and change of redox potential towards mildly reducing conditions (Taylor and Curtis, 1995 and Taylor and Macquaker, 2000). Such conditions are prevailed at or just below sediment-sea water interface, where the diffusional exchange can occur between the sediments and the overlying water and this decreases the pH and Eh of the interstitial pore water of the deposited precursor materials. As a result of low organic matter content, these mild changes in the composition of the interstitial water and the authigenesis of new minerals during the early (post-oxic) diagenesis are volumetrically small.

The low Eh enhances the dissolution of iron, manganese and other trace elements that are released from the deposited iron-rich clays and amorphous iron oxyhydroxides substrates into the interstitial pore solution (i.e. $Fe^{3+} \rightarrow Fe^{2+}$ and $Mn^{4+} \rightarrow Mn^{2+}$). Simultaneously, the ion such as silicic acid is librated from the original iron-rich clays and concentrated with the $Fe^{2+}$ and $Mn^{2+}$ ions in the pore solutions. Also, the silicic acid is adsorped and fixed on the iron oxyhydroxides and ferrihydrite surface by Fe–O–Si bond. The stability of the ferrihydrite precipitates is maintained by the adsorption of silicate species and organic matter. These adsorpates prevent or retard the ferrihydrite precipitates to develop more ordered and stable crystalline phases such as goethite and hematite (Cornell and Schwertmann, 1996). The Al is stable and is retained as Al-rich residue or isolated kaolinitic patches within the iron oxyhydroxides domains.

The interstitial pore solution (rich in $Fe^{2+}$) reacts with the remaining iron-rich clays and ferrihyrite precipitates (rich in Fe and Al) with minor addition of Mg, Ba and K to cause progressive alteration and neoformation of new authigenic nascent glauconitic clay mineral pases of variable composition and internal structures (Oddin and Matter, 1981 and Mesaed and Surour, 2000). The syn-sedimentary reworking from surface layers enhances re-suspension and degradation of the organic matter in the surface sediments and the continued re-oxidation of the reduced iron. The sediment reworking and re-suspension may liberate the relatively soluble Mg, K, Ca and Ba into the pore and sea water.

The progressive stages of organic matter degradation within the precursor iron-rich clays and yellow amorphous iron oxyhydroxides led to the development of *in situ* peloidal and ooidal structures. Such structures appear to be developed as faint to dark brown organic-rich windows within the yellow amorphous iron oxyhydroxide matrix. The distribution of these windows is relatively random and may reflect the heterogeneous distribution of the microbial and organic remains. In the initial stages of the organic matter degradation, these windows grow into *in situ*, internally massive peloidal structures of rounded to elliptical shapes and of variable sizes (Plate 5A). These peloidal structures represent the first

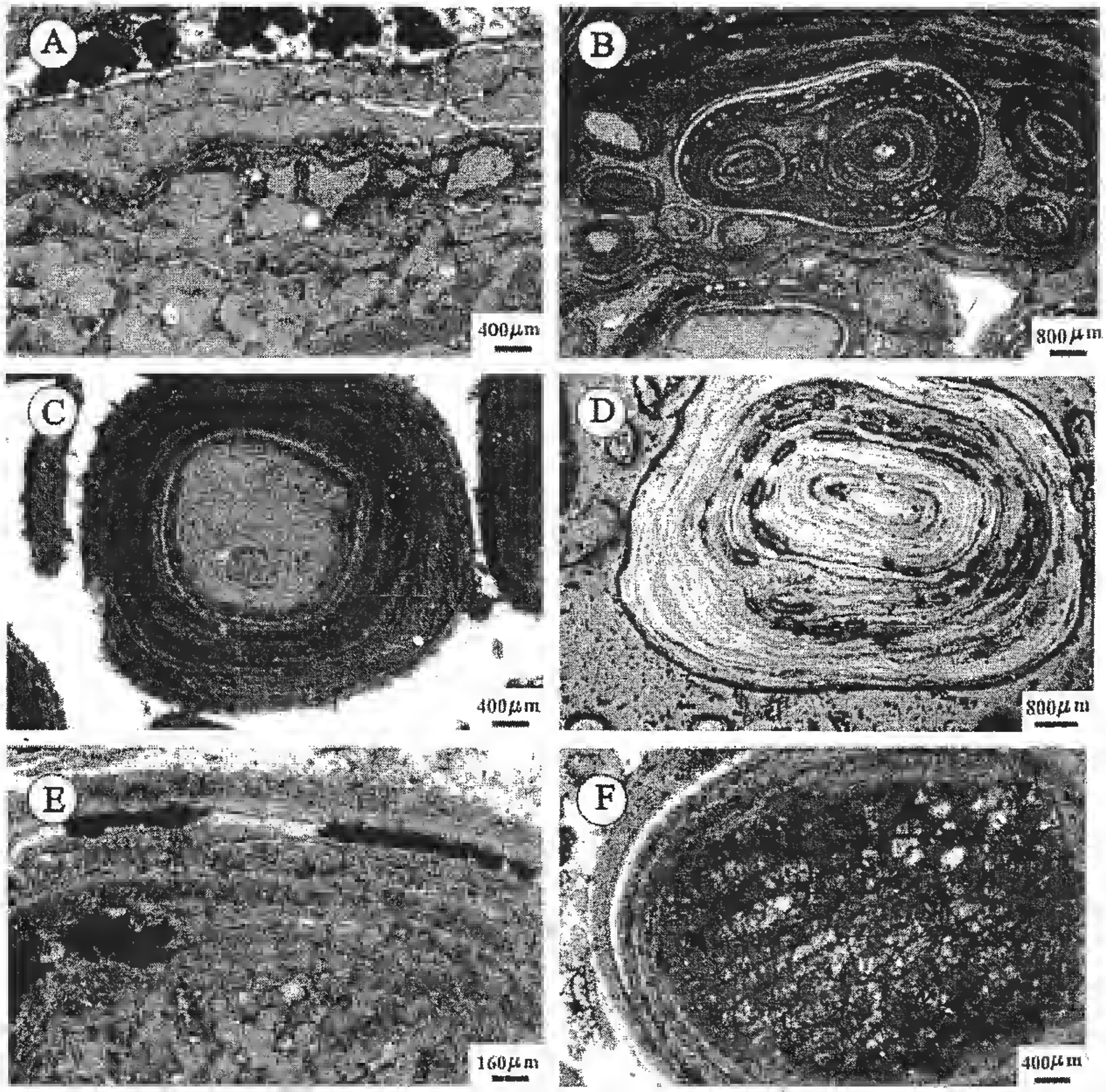


Plate 5. A) *In situ* pelletization of the yellow amorphous iron oxyhydroxide matrix. Isolated Mn-rich patches are recorded in the upper part, PPL; B) *In situ* formed ooids, within the stromatolitic laminae, containing elongated parallel intercortical voids, PPL; C) Ooid cortical lamina showing a centripetal growth. The growth of dark brown cortical laminae converge inward toward a pseudo-core (relicts of the original yellow amorphous iron oxyhydroxide matrix), PPL; D) *In situ* formed ferriferous oncoids showing intercortical voids formed as a result of microbial fermentation of organic matter, R.L.; E) Close-up view of the internal ooid structure showing the gradational contact between the cortical laminae. Notice the growth of thin discontinuous Mn-rich patches aligned parallel to cortical laminae, PPL; F) Authigenesis of glauconitic smectite within the semi-confined micro-pores of a coralline algal fragment during the early diagenetic changes, PPL.
PPL = Plane Polarized Light R. L. = Reflected Light

step for further growth of the *in situ* ooidal structures by developing of internal cortical laminae (Plate 5B). The ooid cortical laminae show a centripetal growth orientation, i.e. the growths of the cortical laminae converge inward toward a center (Plate 5C). This growth pattern may or may not leave behind a pseudo-core of the original precursor yellow amorphous iron oxyhydroxide. These ooid cortical laminae consist of organic-rich discontinuous patches and domains alternated with light yellow organic-poor amorphous iron oxyhydroxide laminae. The close-up microscopic investigations of these ooids reveal the presence of the following features:

a) The organic rich domains consist of faint to dark brown and/or olive green iron-rich glauconitic smectite clays with scattered degraded microbial remains of rounded coccoid cells and filamentous cyanobacterial remains that persist during the diagenetic processes (Plate 5B).
b) The presence of gradual contacts between the organic-rich and organic-poor laminae and between the cortex and the inner pseudo-core and the surrounding amorphous iron oxyhydroxide matrix (Plate 5C).
c) Few ooids contain inter-cortical voids and cavities, which are considered as gas bubbles and are most probably growing during the development of the cortical laminae by the bacterial decomposition and microbial fermentation of organic matter (Plate 5D). These voids are aligned parallel to the cortical laminoe due to the re-arrangement and segregation of the original precursor materials together with newly formed authigenic glauconitic clay minerals.
d) The ooids have different sizes and vary from rounded, oblate to elliptical shapes as well as spastolithic forms. The spastolithic ooidal forms are most probably related to the compactional squashing during the early diagenetic processes.
e) Black discontinuous patches, domains and laminae of high Mn and Ti and low Fe content (Plate 5E) are aligned parallel to the ooid cortical laminae or show a characteristic displacive growth, which led to the desiccation and destruction of the individual cortical laminae. Ti is released to the pore water in the near-shore oxic zone. It is removed from the pore water under reducing conditions below the oxic zone and thus tends to accumulate in sediments forming under reducing conditions. In these conditions, Ti behaves like V and Cr during the early diagenetic changes (Shaw *et al.*1990). The high content of Ti in the Mn-rich laminae may indicate that the Ti is preconcentrated during the lateritic weathering of the source continental areas (Cenomanian clastics) and the Ti is carried by detrital particles into the depositional sites (Maynard, 1986).
f) The textural and internal microfabric evidences reveal neither tangential nor radial internal structures.
g) The biogenic activities by the burrowing microorganisms are obvious, where the structures of few ooids are thoroughly burrowed and this may indicate a calm water energy and low rate of sedimentation and clastic input during the formation of theses ooids and peloids.

The internal structures and mode of ooid formation are similar to the *in situ* (autochthonous) accreted ooids described by Chauvel and Guerrak (1989); Young (1989), El Aref *et al.* (1996 and 1999) and Helba *et al.* (2001 and 2003). Also, these *in situ* formed ooids can be correlated with the similar diagenetic ooids and pisoids described by Carrozi (1960), who related the oolitic structures to the rearrangement and adjustment of the colloidal porticles around o point during deposition or in early diagenetic stages. These ooids and peloids are *in situ* reworked, where the mud matrix has been winnowed away and concentrated in a moderately to well sorted and grain-supported ooidal and peloidal ironstones. So, these ooids and peloids are considered as para-autochthonous grains.The development of ferriferous ooids, peloids and oncoids within the same microbial mat is suggested by the similarity of the mineralized fossil microbial structures of both coated grains and the surrounding matrix and may suggest a similar origin (Dahanayake and Krumbein, 1986).

2) Early diagenetic replacement of the skeletal particles

The post-oxic (weakly reducing) diagenetic changes are also dominated within the semi-confined micro-cavities of the foraminiferal tests and bioclastic debris, forming nascent glauconitic clays (Plate 5F). These diagenetic changes may facilitate dissolution and/or diagenetic replacement of the original calcareous (aragonitic) wall structures. The dissolution process is often related to the oxidation-reduction reactions. The carbonic acid ($H_2CO_3$) is produced by the oxidation of organic matter to $CO_2$, which combines with $H_2O$ to form ($H_2CO_3$) and which in turn partially dissociates to $H^+$ and $HCO_3^-$. During these weakly reducing conditions, the pH decreases and the rate of dissolution of calcite increases. The original iron-rich clays and amorphous iron oxyhydroxides (precursor materials) are diagenetically transformed into greenish brown organic-rich glauconitic clays as a result of organic matter degradation.

Modes Of Fossil Preservation

Two modes of fossil preservation are recorded within the ironstone succession of the Ghorahi ironstones, including:

1- Ferruginized fossil molds and casts

The majority of the macrofossils (whole shell and bioclasts), which include pelecypods, gastropods, echinoderms plates and spines and skeletal algae, are preserved as fossil molds and casts. These modes of preservations result from the dissolution of the original calcareous (aragonitic) wall structures after filling of the intra- and inter-skeletal porosity hy iron-rich clays and amorphous iron oxyhydroxides (precursor materlals). The dissolution of the calcareous wall structures will give rise to various hiomouldic cavities of different shapes and dimensions.

2- Ferruginized original hard parts

The filling of the internal chamherlets of the foraminiferal tests (i.e. nummulitids, alveolinids, meliolids and operculins) and the suhsequent replacement of the original calcareous wall structures hy the amorphous iron oxyhydroxides will give rise to ferruginized foraminiferal tests that are still preserve their external morphology. The most common forams are the nummulitic tests that are characterized hy their lensoidal shapes and still preserve the internal diagnostic fihro-radiated wall structures and external morphology. Few skeletal particles and hioclastic dehris are enveloped hy multilayered, micrometric and irregular coatings and various micro-stromatolitic structures. The iron oxyhydroxide coatings are enriched in mineralized and degraded filamentous and coccoid cyanohacterial cells and capsules.

## SUMMARY AND CONCLUSION

Ghorahi ironstone succession was deposited in lagoonal and peritidal environments of shallow oxygenated, normal to hrackish water and within a neutral to alkaline medium. This depositional system is considered as an ideal site for microbe growtb. The various microbial structures are developed from suspensions under calm water condition in areas of low tidal Influences, low or negligihle sedimentation rate. The shallow sea bottom is colonized by benthic microbiota, prohably Fe-depositing benthic bacteria and cyanohacteria, living at the water-sediment interface. These microhes flourish in a low-energy water condition and coat the mineral grains of the depositional surfaces forming organic coatings or "biofilm". The microhes produce copious amounts of EPS that form an adhesive mucilage and attaches to suhstrates. It also leads to sediment trapping and mineral precipitation. The cyanohacteria are of two types; 1) filamentous cyanohacteria and 2) coccoid cyanohacteria of rounded, elliptical and fusiform shapes.

In the central sector (Tidal flat environment), the erect cyanohacterial filaments cause trapping of the fine-grained sedimentary particles held in iron-ricb suspensions hy tidal current through either simple physical hlockage (haffling) of particle movement or hiochemical adsorption on and in EPS to hecome agglutinated and stahilized against erosion.

Based on the morphologies, microfabrics and facies associations, the microbialites are subdivided into three main morpho-types: 1) Ferruginous stromatolitic microbialites, 2) Ferriferous concentrically laminated microbialites (ferriferous oncoids, and micro-oncoids (ooids)), and 3) Ferriferous peloids.

The internal microfabric analyses of the ferriferous oolds and oncoids reveal that tbey are *in situ* formed (autochthonous) grains developed durlng the action of benthic microhes (hacteria and cyanohacteria). The suhsequent early diagenetic processes contrihute in the final accentuation of these ferriferous grains. The microscopic evidences indicating the *in situ* microhial origin of tbese ferriferous grains.

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# التراكيب الميكروبية و ميكانيكية التكوين العضوية للأحجار الحديدية التابعة لعصر الإيوسين بمنطقة جبل غرابى، منخفض الواحات البحرية، الصحراء الغربية، مصر.

مرتضى مراد طه العارف*، على عبد اللطيف حسن مساعد*، محمد عبد العزيز خليل**، وليد سمير هندى سلامة*

*قسم الجيولوجيا- كلية العلوم- جامعة القاهرة

**شركة الحديد و الصلب المصرية، قطاع المناجم، الواحات البحرية

## الملخص

تهدف هذه الدراسة إلى توضيح الدور الفعال للكائنات الحية الدقيقة (الميكروب)، متمثلة فى البكتريا الهوائية المنتشرة على قاع البحر، أثناء وبعد عمليات الترسيب فى تكوين السحنات الحديدية الطينية و الحبيبية بمنطقة جبل غرابى، الواحات البحرية، الصحراء الغربية، مصر.

أظهر التحليل السحنى و الوضع الترسيبى للرواسب الحديدية أنها تتكون من عدة سحنات حديدية طينية و سحنات حديدية حبيبية غنية بالسرئيات و الأونكويدز ومختلطة مع حفريات حديدية من الفورا مينيفرا القاعية الكبيرة و بعض الهياكل الطحلبية تكررت فى تتابعين مختلفين يفصلهما سطح عدم توافق تأثر بعوامل تعرية كارستية و لاتيريتية أدت إلى تغير فى التركيب الأصلى للسحنات.

تم تقسيم التراكيب الترسيبية الميكروبية إلى ثلاثة أشكال:

١- أشكال حديدية ميكروبية استروماتوليتية مسطحة و قبابية تكونت تحت ظروف ترسيبية هادئة على مسطحات المد الشاطنية فى القطاع الأوسط.

٢- أشكال حديدية ميكروبية حبيبية و تشمل السرئيات و الأونكويدز، بعضها يحتوى على أنوية مركزية انتقلت لأماكن الترسيب بفعل تيارات المد و الجزر و التيارات العاصفة. أوضح التشريح الداخلى والشكل الخارجى للسرئيات و الأونكويدزأنها مكانية التكوين و تتحرك لمسافات قصيرة أثناء الترسيب.

٣- أشكال حديدية ميكروبية حبيبية (بيلويدز) و تمثل المرحلة الأولية لنمو السرئيات.

و تعتبر السيانوبكتريا بنوعيها المستدير و الخيطى أهم الكائنات الدقيقة المؤثرة فى ترسيب أكاسيد الحديد المائية الغير متبلورة إما بطريقة فيزيائية عن طريق التقاط وتجميع و تثبيت الجزيئات الدقيقة لأكاسيد الحديد المائية الغير متبلورة من المحلول الغروى أو بطريقة بيوكيميائية عن طريق امتزاز أكاسيد الحديد المائية الغير متبلورة على أو بداخل جدران الخلايا البكتيرية.

أيضا يمتد دور السيانوبكتريا إلى المرحلة المبكرة من عمليات مابعد الترسيب حيث أنها تعمل على تحلل بقايا المواد العضوية و التى ينتج عنها بيئة اختزالية ضعيفة و تغير فى الظروف الكيميائية و أيضا ينتج عنها ذوبان للهياكل الكلسية للحفريات و إحلالها بمركبات الحديد المائية الغير متبلورة.